An efficient and highly performing memristor-based reservoir computing system

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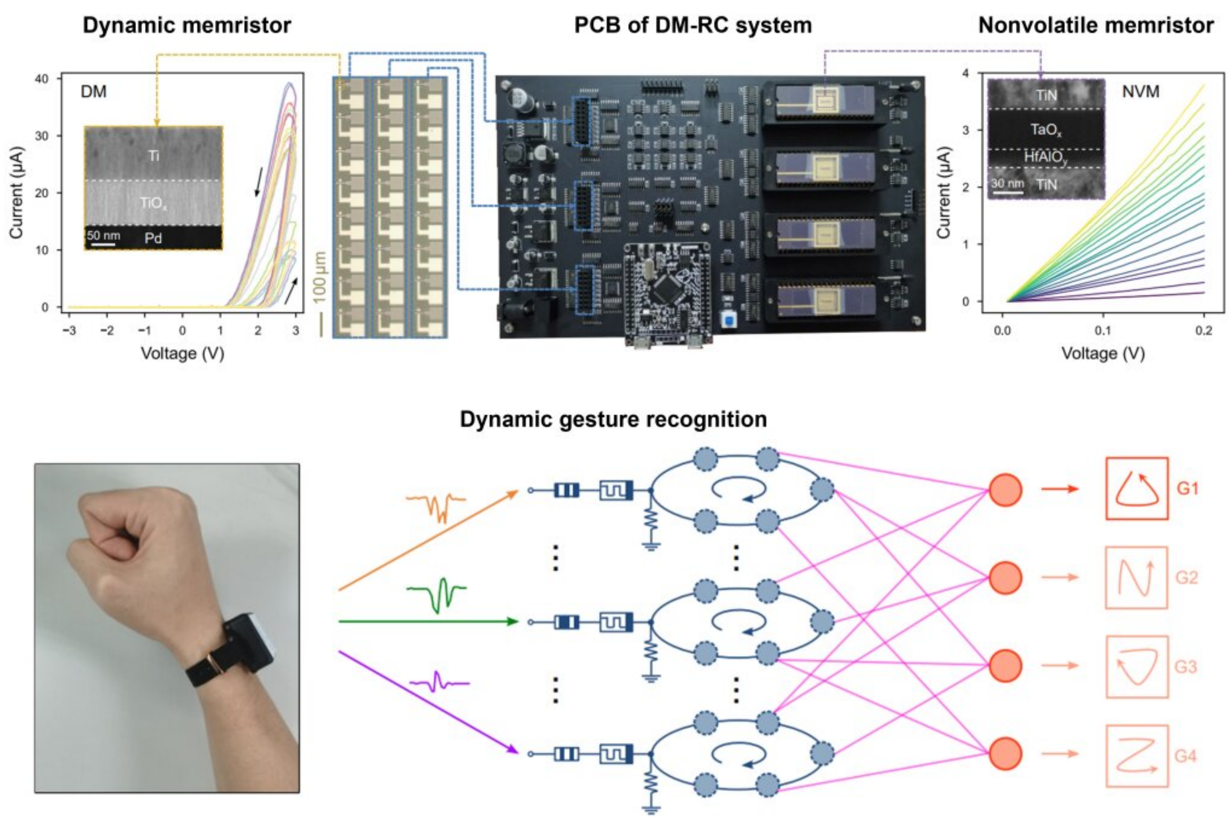

Figure summarizing the hardware architecture and application of the DM-RC system. Credit: Zhong et al.

Reservoir computing (RC) is an approach for building computer systems inspired by current knowledge of the human brain. Neuromorphic computing architectures based on this approach are comprised of dynamic physical nodes, which combined can process spatiotemporal signals.

Researchers at Tsinghua University in China have recently created a new RC system based on memristors, electrical components that regulate the flow of electrical current in a circuit, while also recording the amount of charge that previously flowed through it. This RC system, introduced in a paper published in *Nature Electronics*, has been found to achieve remarkable results, both in terms of performance and efficiency.

"The basic architecture of our memristor RC system comes from our earlier work published in *Nature Communications*, where we validated the feasibility of building analog reservoir layer with dynamic memristors," Jianshi Tang, one of the researchers who carried out the study, told TechXplore. "In this new work, we further build the analog readout layer with non-volatile memristors and integrate it with the dynamic memristor array-based parallel reservoir layer to implement a fully analog RC system."

The RC system created by Tang and his colleagues is based on 24 dynamic memristors (DMs), which are connected into a physical reservoir. Its read-out layer, on the other hand, is comprised of 2048x4 non-volatile memristors (NVMs).

"Each DM in the DM-RC system is a physical system with computing power (called a DM node), which can generate rich reservoir states through a time-multiplexing process," Tang explained. "These reservoir states are then directly fed into the NVM array for multiply-accumulate (MAC) operations in the analog domain, resulting in the final output."

Tang and his colleagues evaluated the performance of their dynamic memristor-based RC system by using it to run a deep learning model on two spatiotemporal signal processing tasks. They found that it achieved remarkably high classification accuracies of 96.6% and 97.9% on arrythmia detection and dynamic gesture recognition tasks, respectively.

"Compared with the digital RC system, our fully analog RC system has equivalent performance in accuracy but saves more than 99.9% of power consumption (22.2µW vs 29.4mW)," Tang said. "A unique feature of our work is that, to construct a complete fully analog RC system, we used two distinct types of memristors: DMs as the parallel reservoirs and NVM arrays as the readout layer, without the aid of any digital components, such as those used in previously reported hardware RC systems."

The unique system architecture devised by this team of researchers greatly reduces the complexity of RC approaches, while also significantly lowering power consumption. In the future, it could thus enable simpler and larger-scale RC hardware implementations.

"Optimized non-volatile memristors with excellent analog switching characteristics were integrated to fulfill end-to-end analog signal transmission and processing throughout the RC system," Tang said. "Also, based on the noise model extracted from our memristor arrays, a noise-aware linear regression method was used to train the output weight and effectively mitigate the accuracy loss (less than 2%) caused by the non-ideal characteristics of memristors."

Tang and his colleagues were the first to demonstrate fully analog signal processing in real-time using an RC hardware system. This demonstration ultimately allowed them to reliably evaluate their system's overall power consumption.

"By correlating the experimental data with model simulations, the working mechanism of DM-RC system, we were also able to find out more about the relationship between the electrical characteristics of physical nodes and the system performance," Tang said. "More specifically, we unveiled two key features (i.e., threshold and window) that were extracted from the characteristics of dynamic memristor nodes had a significant impact on the reservoir quality."

After identifying two features that affected their RC system's performance, Tang and his colleagues were able to define ranges of these two features that led to optimal RC performance. Combined, these ranges and their other findings could serve as a guide for the future design and optimization of RC systems. This could help to unlock their potential for edge computing, along with other applications that require low power consumption and affordable hardware costs.

"In the future, the entire DM-RC system could be miniaturized and monolithically integrated on chip to further reduce its power consumption and computing latency," Tang added. "In addition, a deeper and more sophisticated RC system can be constructed using DM-RC system as a basic unit, which would further enhance the system performance because of richer reservoir states and stronger memory capacity."

More information: Yanan Zhong et al, A memristor-based analogue reservoir computing system for real-time and power-efficient signal processing, *Nature Electronics* (2022). DOI: 10.1038/s41928-022-00838-3

Yanan Zhong et al, Dynamic memristor-based reservoir computing for high-efficiency temporal signal processing, *Nature Communications* (2021). DOI: 10.1038/s41467-020-20692-1